INEEL/CON-04-02357
PREPRINT

3-D Thermal Evaluations For A Fueled Experiment In The Advanced Test Reactor

Idaho National Engineering and Environmental Laboratory

Richard G. Ambrosek
Gray S. Chang
Debbie J. Utterbeck

October 3-6, 2004

America's Nuclear Energy Symposium 2004

Proceeding of
ANES/SENA 2004 Symposium
Miami Beach, Florida – October 3 – 6, 2004
2c3-RTTR10

3-D THERMAL EVALUATIONS FOR a FUELED EXPERIMENT in the ADVANCED TEST REACTOR

Richard G. Ambrosek
Idaho National Engineering &
Environmental Laboratory
P.O. Box 1625
Idaho Falls, Idaho 83415
Phone: 208-526-7710
Fax: 208-525-0528
rga@inel.gov

Gray S. Chang
Idaho National Engineering &
Environmental Laboratory
P.O. Box 1625
Idaho Falls, Idaho 83415
Phone: 208-526-7646
Fax: 208-526-0528
gsc@inel.gov

Debbie J. Utterbeck
Idaho National Engineering &
Environmental Laboratory
P.O. Box 1625
Idaho Falls, Idaho 83415
Phone: 208-526-2782
Fax: 208-525-0528
udu@inel.gov

INTRODUCTION

The DOE Advanced Fuel Cycle Initiative and Generation IV reactor programs are developing new fuel types for use in the current Light Water Reactors and future advanced reactor concepts. The Advanced Gas Reactor program is planning to test fuel to be used in the Next Generation Nuclear Plant (NGNP) nuclear reactor. Preliminary information for assessing performance of the fuel will be obtained from irradiations performed in the Advanced Test Reactor large “B” experimental facility.

A test configurations has been identified for demonstrating fuel types typical of gas cooled reactors or fast reactors that may play a role in closing the fuel cycle or increasing efficiency via high temperature operation Plans are to have 6 capsules, each containing 12 compacts, for the test configuration. Each capsule will have its own temperature control system. Passing a helium-neon gas through the void regions between the fuel compacts and the graphite carrier and between the graphite carrier and the capsule wall will control temperature. This design with three compacts per axial level was evaluated for thermal performance to ascertain the temperature distributions in the capsule and test specimens with heating rates that encompass the range of initial heat generation rates..

COMPONENT DESCRIPTIONS

The design used for these evaluations consisted of three compacts at each axial level. The fuel compacts were one inch high and 0.500 inches in diameter yielding a four inch high fuel stack. All internal components were contained inside a stainless steel vessel with an outer diameter of 1.375 inches and a wall thickness of 0.050 inches. The total assembly (capsule) was contained in a 1.5-inch irradiation facility. Reactor primary coolant (light water, low temperature) flows between the capsule and the reactor reflector.

The evaluations were performed with a gas gap between the graphite carrier and the capsule wall of 0.025 inches. The gas zone between the compact and the graphite carrier was 0.0025 inches. There were three quarter-inch half cylinders that contain 0.0625-inch diameter gas lines and thermocouple leads. A schematic of the design is shown in Figure 1.

MATERIAL THERMAL- PHYSICAL PROPERTIES

The thermal and physical properties required for the materials were gathered from General Atomics reports, from standard references or from information supplied from the German gas reactor program for Triso-type fuel, graphite materials, and standard materials of construction.

The thermal conductivity for the temperature control gas zone and the zone between the compact and graphite holder was modified to reflect different gases or gas mixtures. The heating rates used to predict the thermal performance were provided by the physics analysis.

COMPUTER CODES

Thermal

The models representing the physical characteristics of the test were developed using the computer code PATRAN. PATRAN has been used as a modeling tool for several years and has been demonstrated to correctly represent the data input. The finite element model was evaluated using the computer code ABAQUS, version 6.4-1 on a SUN computer.

Physics

The physics analyses were performed using the computer code MCNP currently being used for evaluation of experimental programs in the ATR. This is a general Monte Carlo n-particle code written at the Los Alamos National Laboratory. Version 4C of the MCNP code, as described in LA-13709-M, 2000, was used in the evaluation. This version has been verified at the INEEL by benchmarking calculated flux magnitudes with measured flux levels for several experiments and in several test positions of the INEEL Advanced Test Reactor (ATR) core. The MCWO methodology, which applies the Monte-Carlo code MCNP coupled with an isotope depletion code ORIGEN-2, was used to model depletion. This approach has been separately validated for this purpose.

MODEL

Thermal

The AGR-1 test configuration was modeled using PATRAN for construction of the finite element models and ABAQUS was employed to solve the models for the steady state temperatures. The resulting three-dimensional model represents a 120- degree segment of one capsule in the test train assembly within the active core. Heat transfer was modeled from surfaces in contact with flowing primary coolant. Radiation heat transfer was modeled between the compact and the graphite holder and between the graphite holder and the stainless steel containment.

Physics

The configuration of the ATR was modeled to represent the power splits and operating conditions projected for a typical cycle with an East source power of 23.0 MW (typical irradiation Cycle with lobe powers of 18 MW (NW), 18 MW (NE), 25 MW (C), 25MW (SW), and 26 MW (SE)).

The proposed compact irradiation vehicle contains 12 fuel compacts per stack, designated as compacts 1 through 12 in the large B-09 position. The typical fuel compact contained 1410 fuel particles per cubic centimeter for this evaluation. The radial view of the fuel test assembly in the large B-10 is shown in Fig. 1. The axial view of the fuel test assembly is shown in Fig. 2.

RESULTS

Thermal

Steady state analyses were completed for the AGR-1 test train with gas mixtures of 100% Ne, and 100% He with structural heating commensurate with a source power of 23.0 MW. The width of the control gas annulus was varied until the desired operating temperature (~ 1175 °C) was obtained with the respective minimum or maximum heating rate and with Neon or Helium gas, respectively.

The results indicate that the He-Ne system can control the temperature within an acceptable range for compact heating from 50 W/cc to 120 W/cc with the three compacts per axial level configuration. The temperature plots are contained in the Figures 3-8.

Physics

The fuel test capsules with a fuel particle load-packing factor of 35% (1410 particles/cc), He-4 gas coolant, and a graphite holder with natural B4C (6.0 wt%) were assembled in the East large B-10 position. MCNP and ORIGEN-2 were used to calculate power per unit volume (watts per cc) for the 19.7% 235-U enrichment fuel as a function of irradiation time. Because of the depletion of 235-U during irradiation, the fission heat rate will decrease, however depletion of the B4C will result in an increase in the fission heat rate. The combination results in an initial heat rate that is depressed and then a maximum heat rate at approximately 200 days of irradiation. Then as irradiation continues the heat rate will decrease as the 235-U is depleted further. The fission heat rate for the compact which reaches the maximum heating, capsule 3, stack 2, compact 1, varies from 175.9 W/cc to 40.1 W/cc. The total peak heat rate in the graphite holder is approximately 5.9 W/g. Comparison between the case with a graphite holder with no B4C and the graphite holder with natural B_4C (6.0 wt%) case, indicates that the heat rate delta that must be compensated with the control gas is must larger for the case without B4C. The fission power density versus Effective Full Power Days of irradiation for capsule 3, stack 2, compact 1, is plotted in Figure 9.

CONCLUSIONS

The He-Ne control range, with the assumed configuration, results in a control band that will meet programmatic requirements for temperature over the heating range from 50 W/cc to 120 W/cc. This appears to encompass the predicted heat rates for a graphite holder with 6.0-weight percent boron carbide. Based on this it is concluded that the experiment design will allow operation at the specified conditions over the irradiation interval with the derived boron carbide concentration in the graphite holder and the analyzed control annulus gap.

REFERENCES

1. MSC Software Corporation, MSC.PATRAN, Version 8.0, Los Angeles, CA
2. Hibbitt, Karlsson, & Sorensen, Inc., ABAQUS/Standard, Version 6.3-1

Figure 1: Radial cross-section view of the fuel compacts per stack in the test assembly

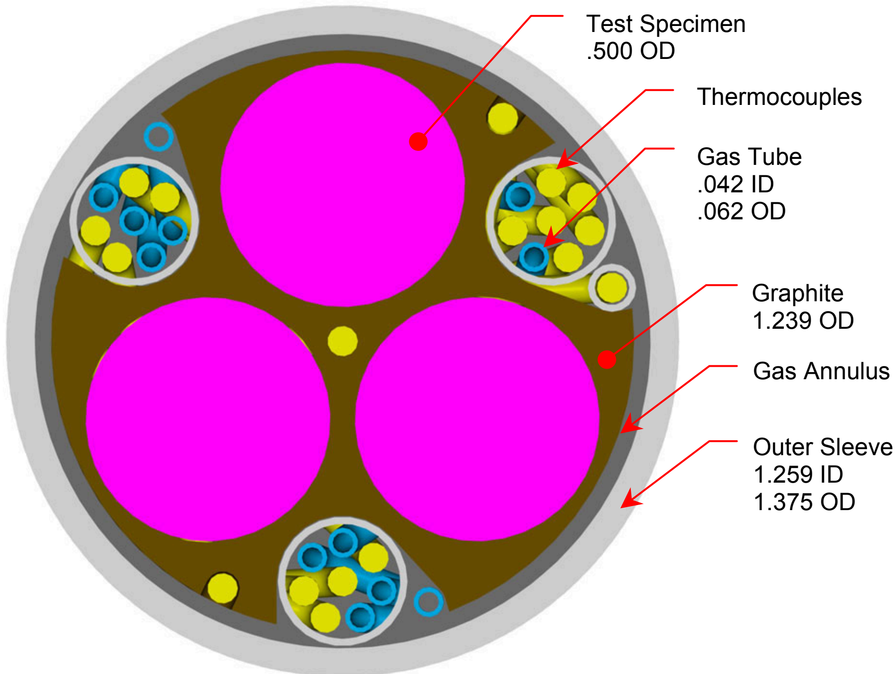

Figure 2: Axial cross-section view of a capsule in a stack

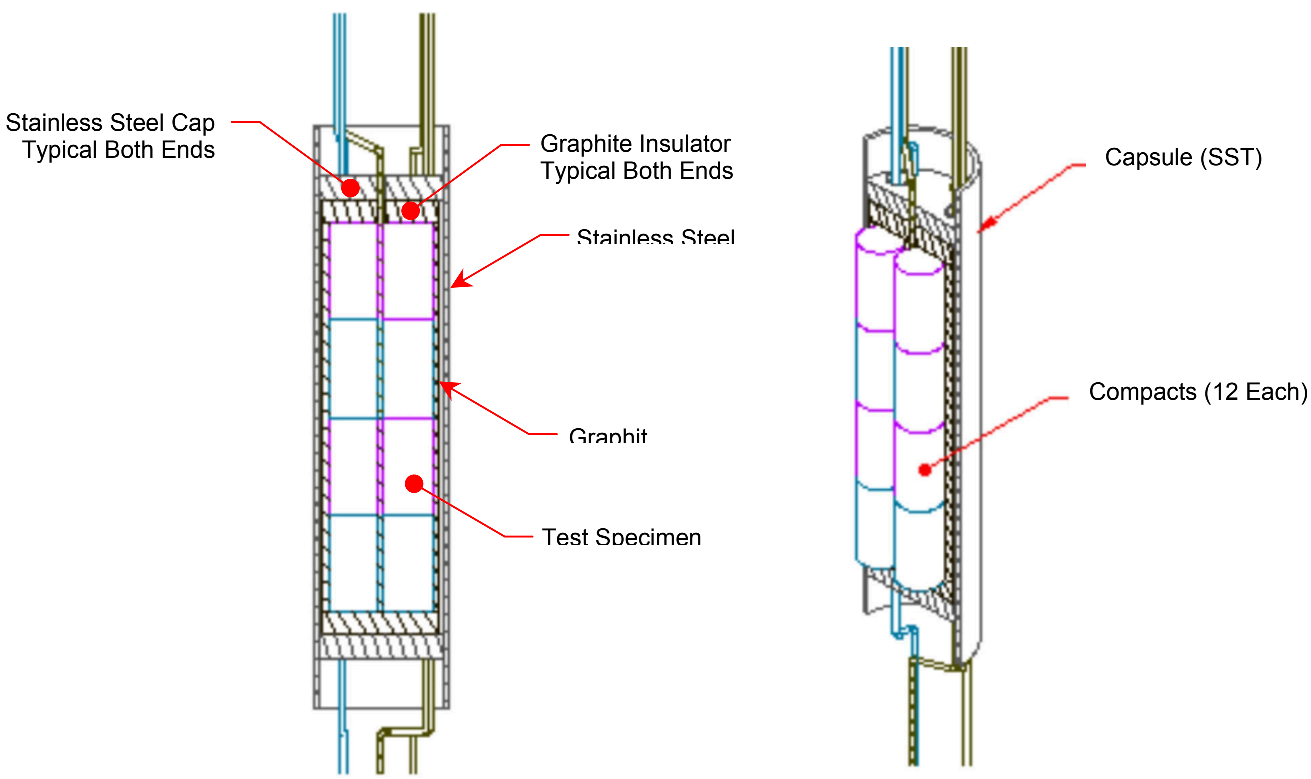

Figure 3. Temperature Distribution in Head with Neon Control Gas

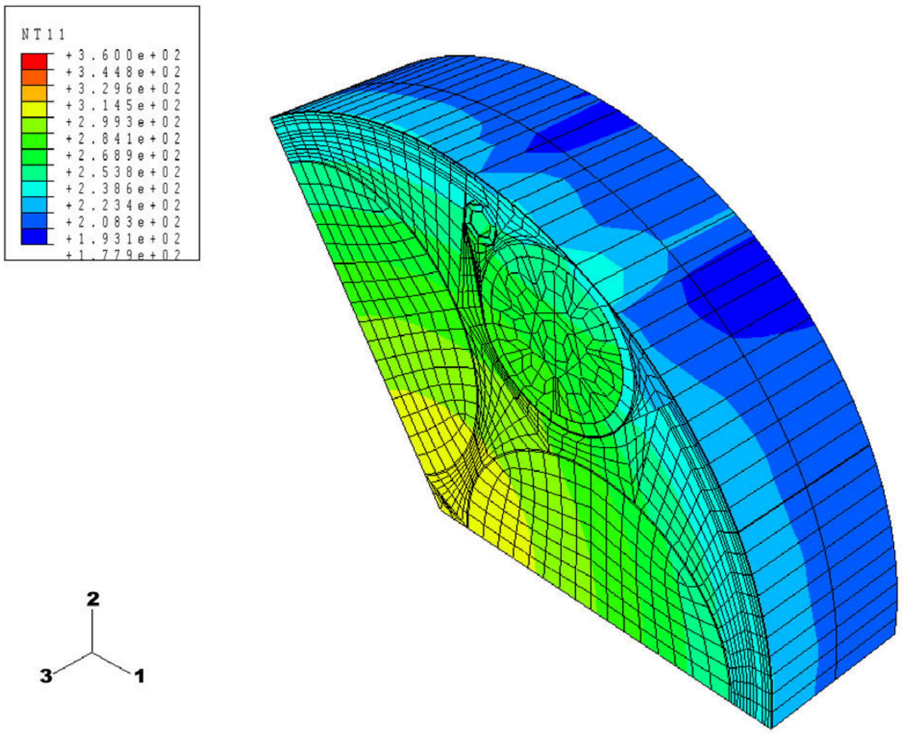

Figure 4. Temperature Distribution in Head with Helium Control Gas

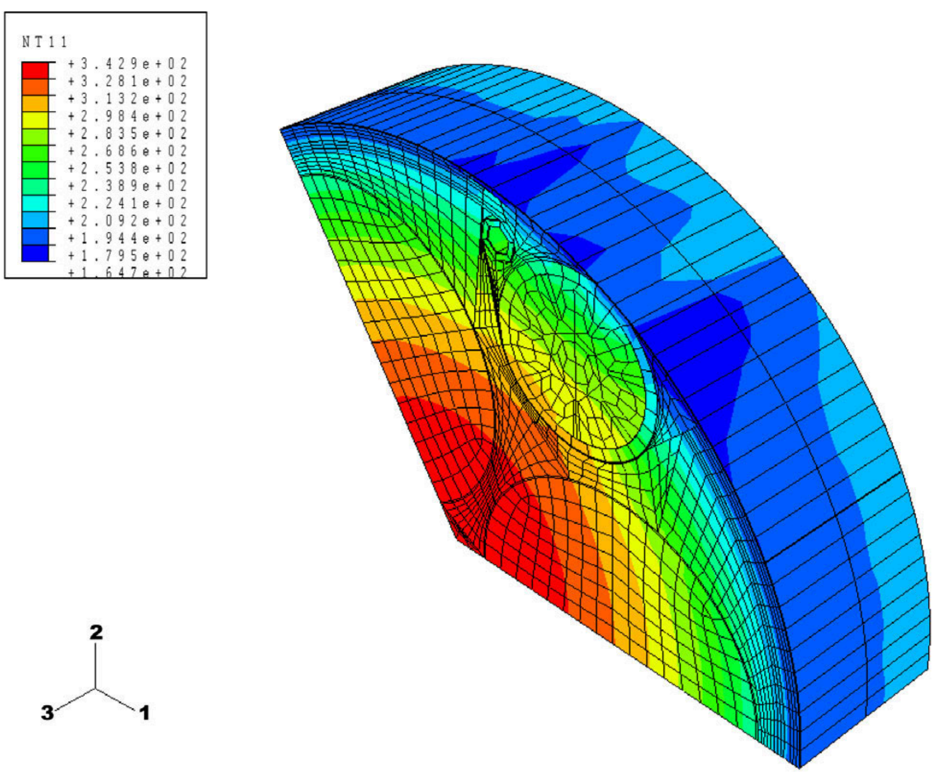

Figure 5. Temperature Distribution in Capsule Shell with Neon Control Gas

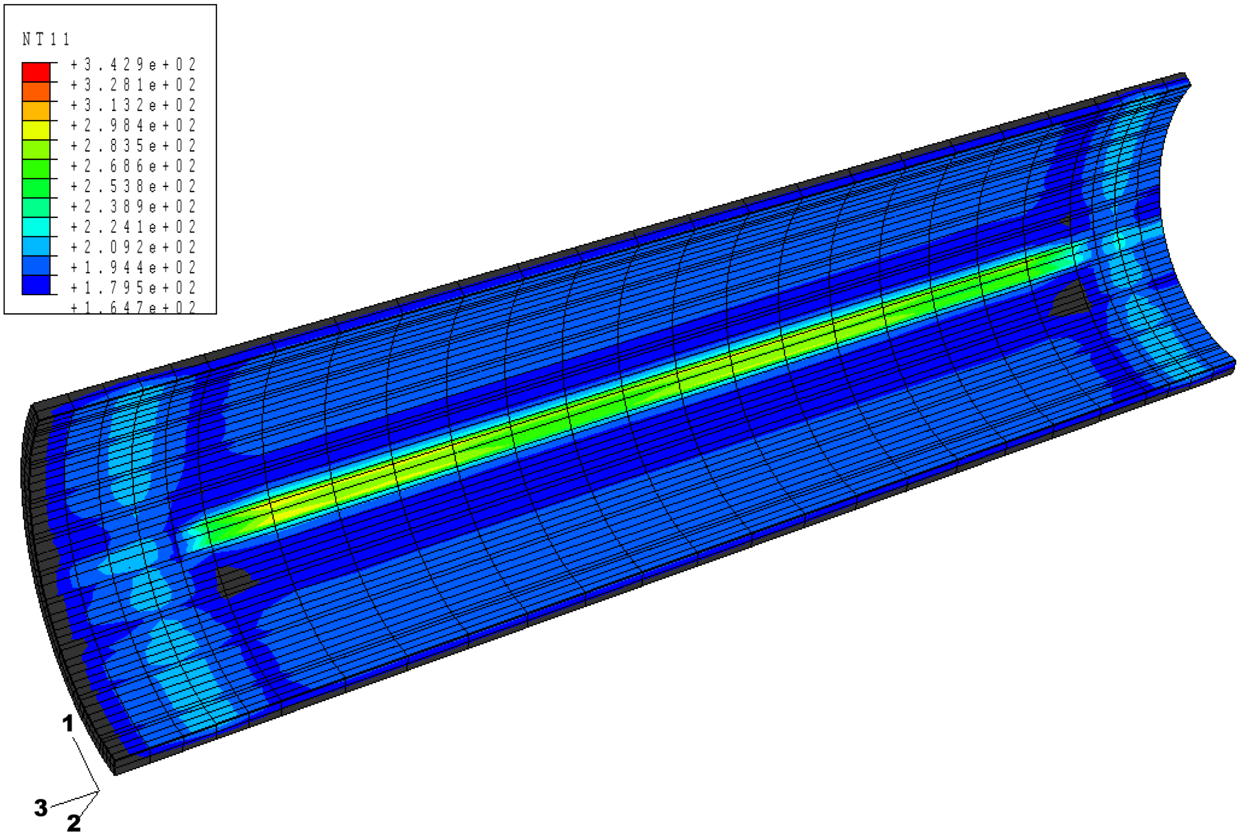

Figure 6:

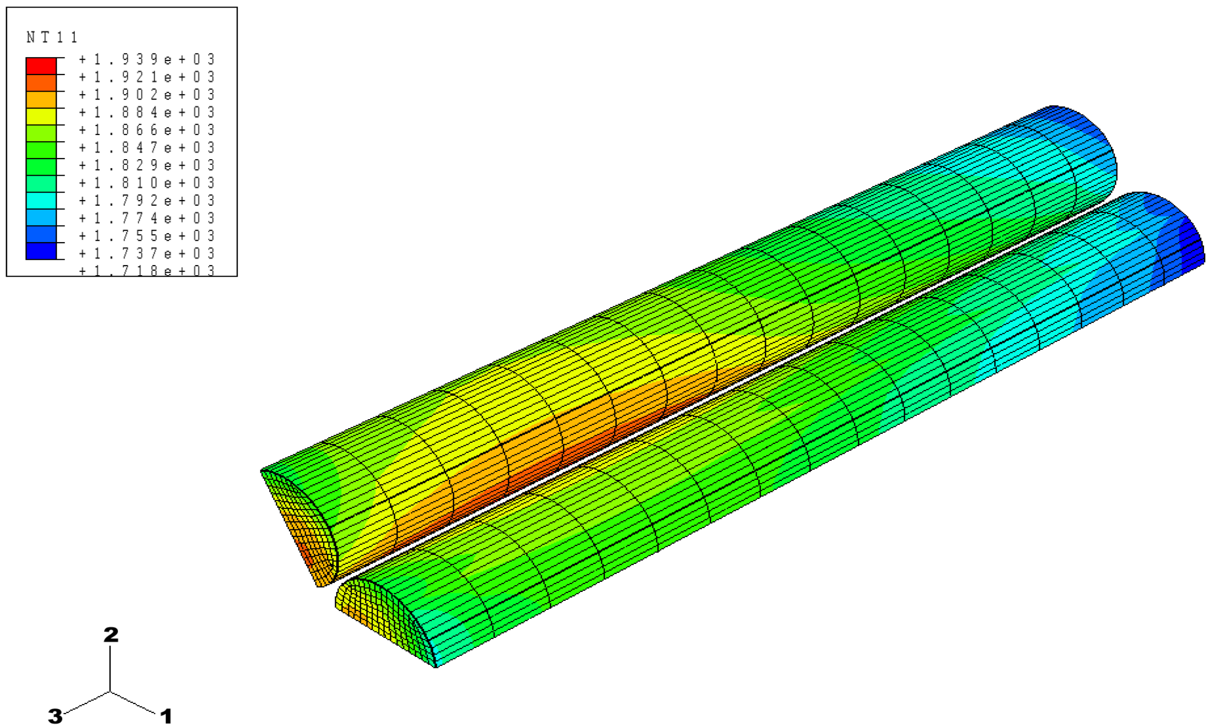

Figure 7.

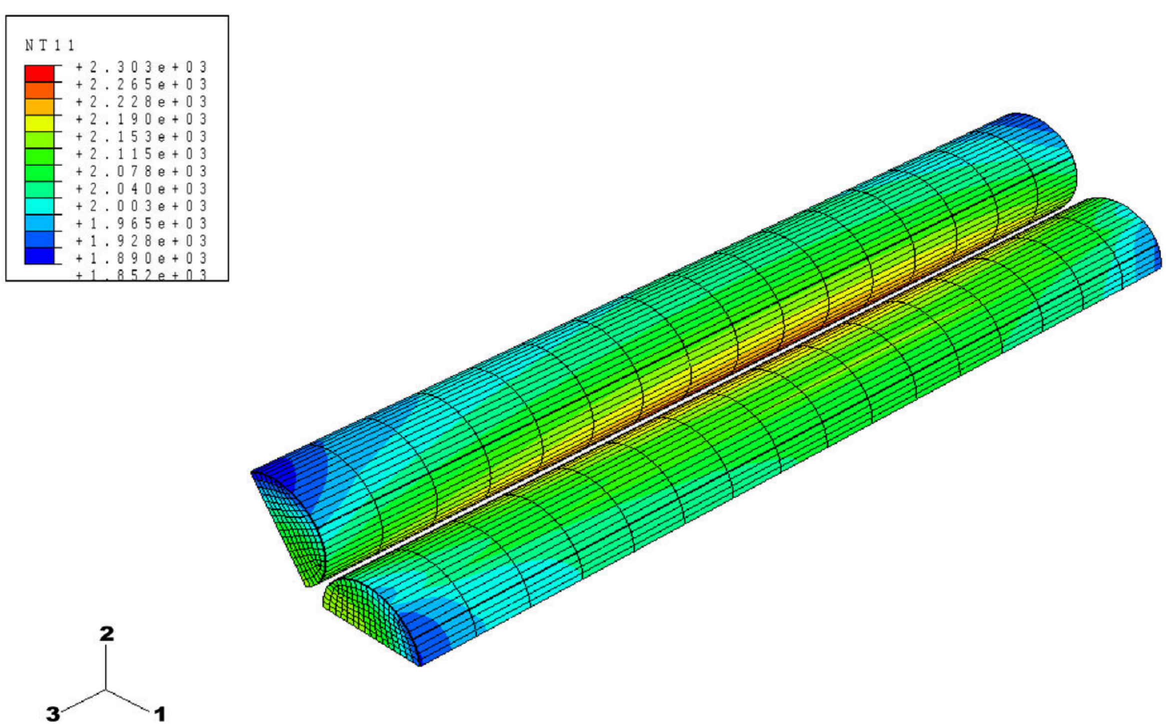

Figure 8.

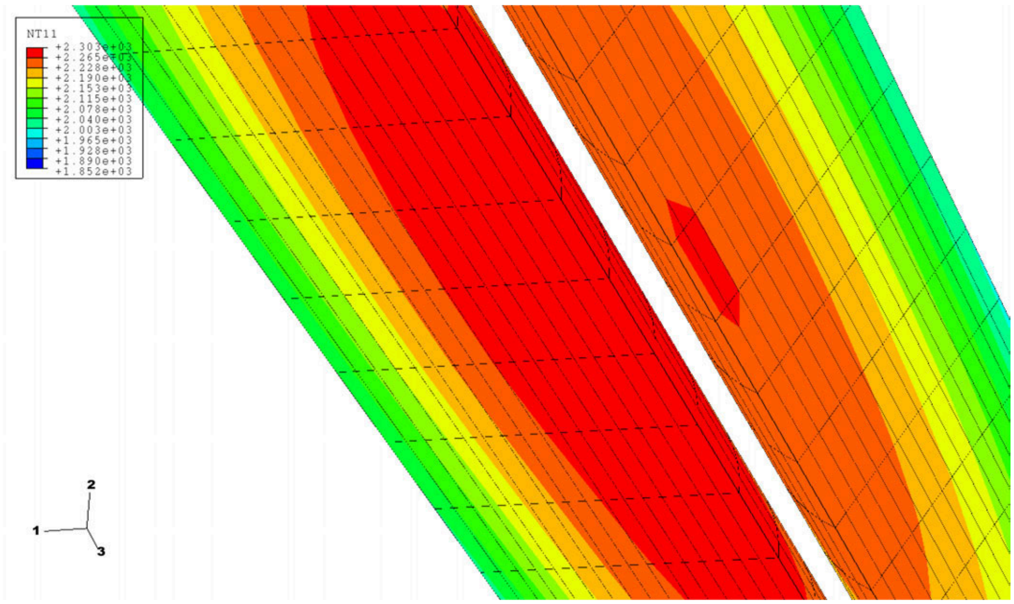

Figure 9.

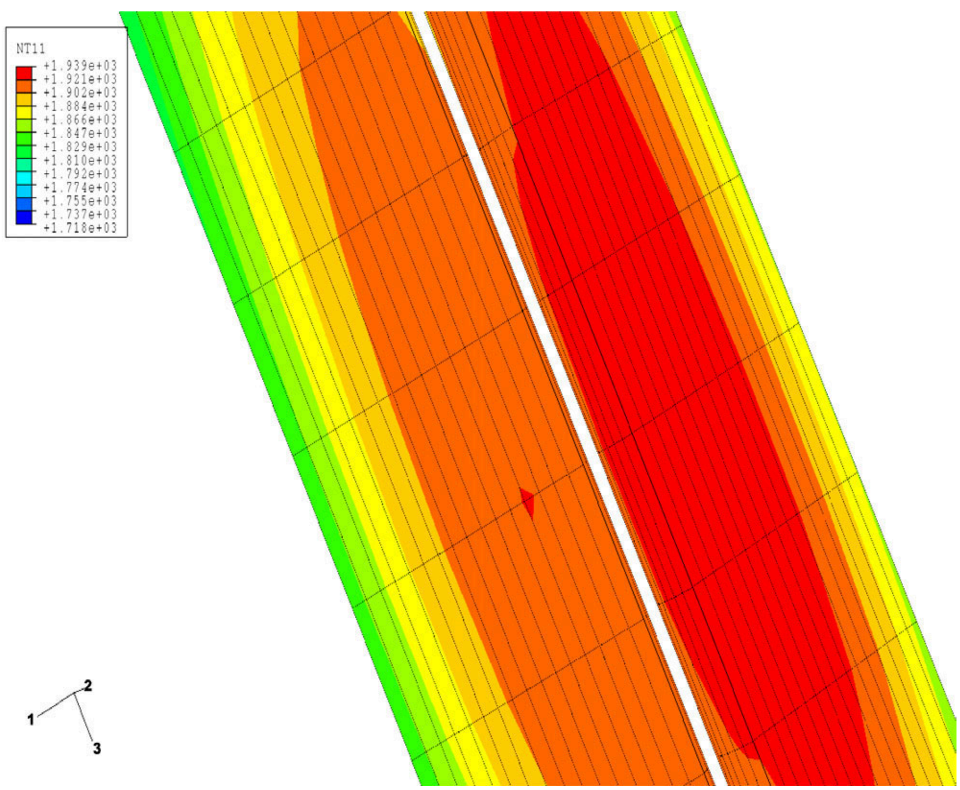

Figure 10.

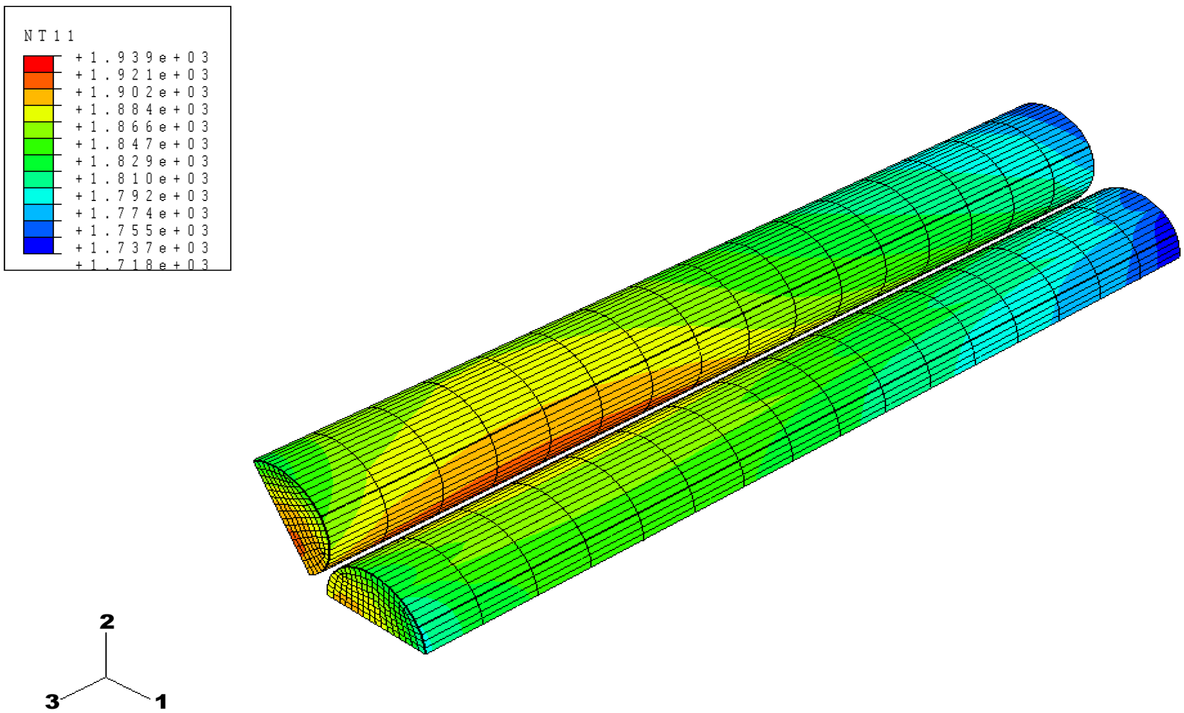

Figure 11.

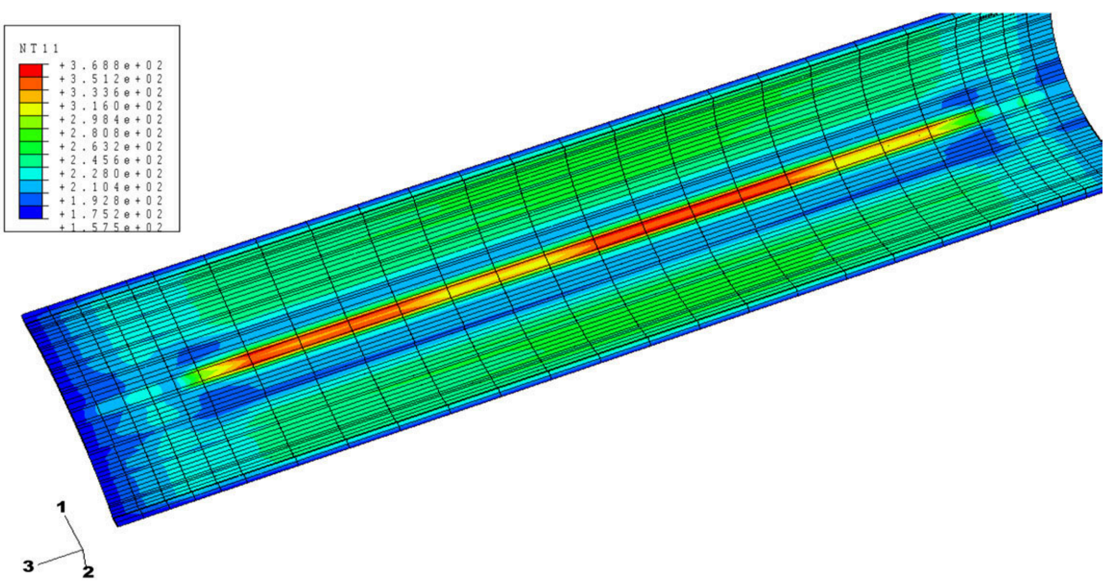

Fig. 12: Stack 3, number 6 fission power density' versus Effective Full Power Days For a graphite holder and a graphite holder with natural B_4C (2.35 wt%)